DOUGLASS ON CLIMATIC CYCLES AND TREE-GROWTH.[1]

By A. J. HENRY.

[Weather Bureau, Washington, D. C., April 1, 1922.]

The investigation described in this monograph is a continuation and a more complete presentation of the subject dealt with in an article in MONTHLY WEATHER REVIEW for June, 1909.[2]

The argument which suggested the investigation was (1) the rings of trees measure the growth; (2) growth depends largely upon the amount of moisture, especially, in a climate where the quantity of moisture is limited; (3) in such countries, therefore, the rings are likely to form a measure of precipitation. Relation to temperature and other weather elements may be very important but precipitation was thought to be the controlling factor in this region. It was, therefore, the element fundamentally considered in the study.

Trees suitable for climatic study.—The trees used were the yellow pine (*Pinus ponderosa*) common to the western Rockies; the sequoias (*Sequoia gigantea*) of central-southern California; Scotch pine (*P. silvestris*); hemlock (*Tsuga canadensis*): Douglas fir (*Pseudotsuga mucronata*).

The studies were begun with the pines of northern Arizona and carried thence to the following parts of northern Europe; South of England; outer coast of Norway, inner coast of Norway, Christiana, Norway; central and south Sweden; Eberswalde, Prussia, Pilsen, Austria, and southern Bavaria. In the United States measurements were also made of trees in Vermont and Oregon.

The details of counting the rings used in the preliminary studies were improved as the investigation proceeded, especially by the discovery and application of a method of cross-identification. By the application of this method greater accuracy was obtained and much greater confidence in the results was attained.

TREATMENT OF THE MEASUREMENTS.

For details of the methods of averaging, standardizing, and smoothing the data the reader must be referred to the original paper; there is one comment as to the smoothing methods that seems to be appropriate.

The author remarks (p. 61):

> In the early part of the work the use of overlapping means was adopted. At the very start, overlapping means of a considerable number, such as 11 or 9, were used. This was quickly changed to overlapping means of 3. * * * However, this was changed to Hann's formula [3] because his formula is normally easier to apply and it gives a little more individuality to each observation.

Correlation between rainfall and tree growth.—The completion of numerous curves of tree growth suggested the following possibilities: (1) In arid climates the annual rings are approximately proportional to the rainfall; (2) in moist-climate groups they vary with the changes of solar activity; (3) in each they are subject to certain cycles or periodic variation.

The reviewer is unable to closely differentiate between 1 and 2 of the above. The first proposition is logical and seems to be well established, at least for northern Arizona.

The second postulates that in humid climates which connote at once more cloud, fog, and rain and less insolation than in arid climates the tree rings vary in accordance with changes in solar activity. It is conceivable that increased solar heat would result in the development of additional cells in the woody fiber of the tree, and, accordingly, we should expect larger rings at time of increased solar heat.

The spectroscopic observations, especially those of Lockyer, indicate that the sun is hotter at time of maximum spots than at minimum. Köppen and others have shown, paradoxical as it may seem, that terrestrial surface temperatures are lower at time of maximum than at minimum. This was explained by Blanford (1875) by suggesting that the air temperature at land stations must be determined not by the quantity of heat that falls on the exterior of the planet but by that which penetrates to the earth's surface, chiefly to the land surface of the globe. The greater part of the earth's surface being, however, one of water the immediate effect of increased heat must be an increase of evaporation and therefore, as a consequence, increased cloud and rainfall. A cloudy atmosphere intercepts a large part of the incoming solar heat and the reevaporation of the fallen rain lowers the temperature of the surface from which it evaporates and that of the stratum of air in immediate contact with it. While the heat liberated by condensation at the cloud levels doubtless prevents cooling at those levels, yet other causes are at work which tend to depress the air temperature at the surface.

It is therefore not easy to find a physical reason for the solar rythm in tree rings, as shown by Doctor Douglass, unless possibly in the precipitation, as we shall point out later.

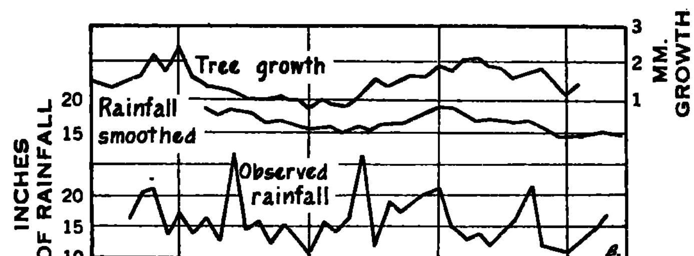

FIG. 1. —Correlation between tree growth and rainfall in smoothed curves: Flagstaff.

The earliest comparison between rainfall and tree growth was made between a subgroup of six trees near Flagstaff, Ariz., and the record of rainfall at Prescott, Ariz., 67 miles distant. The Prescott rainfall record was smoothed by computing nine-year overlapping annual means. The nine-year mean was plotted at the end of the nine-year period rather than at the center. Figure 1 (No. 13 of original) above gives smoothed curves of rainfall and tree growth at the top and the observed rainfall at the bottom.

The rainfall at Prescott for the whole years 1867, 1868, 1869, 1874, and 1875 is missing from the record; the missing records were supplied by the author as follows:

> The Prescott gaps were bridged by plotting the rainfall curves of all records near Prescott and at similar altitudes in Arizona or western New Mexico, and finding enough similarity in many of them to Prescott to make a fair estimate of the actual precipitation at Prescott in the lacking years.

---

[1] Carnegie Institution of Washington, *Publication No. 289.*

[2] Weather cycles in the growth of big trees. See other papers by the same author as follows: Method of estimating rainfall by the growth of trees, *Bull. Amer. Geograph. Soc.*, XLVI:321-335. A photographic periodogram of sunspot numbers, *Astroph. Jour.* XL, No. 3:326-331. A method of estimating rainfall by the growth of trees. The climatic factor as illustrated in arid America, by E. Huntington, *Carnegie Inst. Wash., Pub. No. 192*, Chap. I:101-121. Climatic records in the trunks of trees, *Amer. Forestry*, December, 1917, 732-735. An Optical Periodograph, *Astrophys. Jour.*, XLI:173-186, Evidence of Climatic Effects in the Annual Rings of Trees, *Ecology*, I:24-32.

[3] In a letter to the reviewer the author makes it plain that the expression "Hann's formula" refers to the familiar method of Bloxam as described in *Quar. Jour. Roy. Met. Soc.* 30:95, viz, $b=(a+2b+c)/4$.

The comparison shown in Figure 1 was made because at that time there were not enough rainfall observations for Flagstaff to be of service. Later, when a Weather Bureau station had been in operation for several years, a direct comparison, as shown in Figure 2 (No. 14 of original), was made.

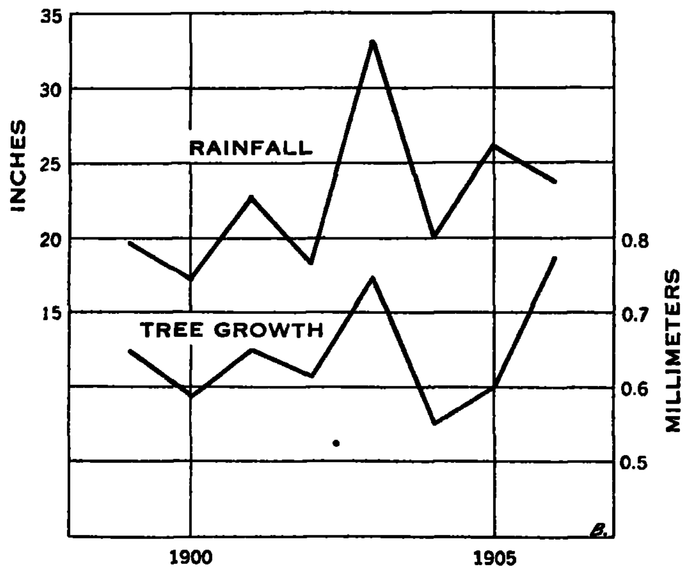

FIG. 2.—Early test of correlation between tree growth and rainfall by years: Flagstaff.

In the above Figure 2 the agreement is remarkably close and there is apparently very little, if any, lag between the occurrence of precipitation and response in tree growth.

The Prescott correlation.—Five subgroups, numbering in all 67 trees located at different points in the vicinity of Prescott, were used. These all cross-identified among themselves both as individuals and as groups with entire success, but in comparison with Prescott rainfall they differed greatly, the group nearest the city showing the best accordance. This group No. V has been plotted to form Figure 3 (No. 7 of original). The rainfall and tree-growth data are both presented unsmoothed.

The accuracy with which the growth of pine trees near Prescott represent the rainfall of that city for 43 years is about 70 per cent, but with a correction for conservation of moisture by the soil this accuracy rises to about 82 per cent.

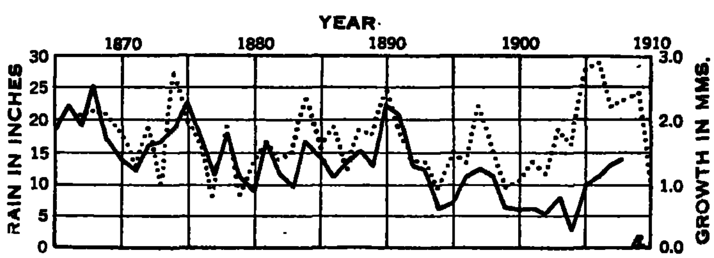

FIG. 3.—Annual rainfall and growth of trees, Group V, at Prescott. Dotted line, rainfall; solid line, tree growth.

In the reviewer's opinion the effect of the conservation of moisture in the dry soil of an arid region would be very difficult of evaluation, except for very favorable and exceptional conditions of soil and local topography. Continuous precipitation and stream-flow measurements in the Wagon Wheel Gap, Colo., watersheds seem to indicate that the conservation of water due to excess of precipitation in any season does not persist much, if any, beyond 8 or 10 months. The author very properly reserves the subject of the moisture content of the soil for further study.

Sequoia correlation with rainfall.—Attempt is made to compare the growth of sequoias with the rainfall of Fresno and San Francisco. The difficulty inherent in this comparison was probably realized by both Huntington and Douglass. The best that can be said of the rainfall of Fresno is that it is the only record available.

The rainfall record of Fresno does not begin until 1882. The San Francisco record, while it began in the early fifties, represents a different rainfall régime from that of Fresno—a station of the Great Valley of California. It is not strange, therefore, that the agreement between the two curves is not as good as at Prescott.

CORRELATION WITH SUN SPOTS.

Under this caption the author remarks (p. 74):

The differential study of the Arizona trees will be taken up in connection with cycles, but can be summarized in the statement that in the last 160 years 10 of the sun-spot maxima and minima have been followed about four years later by pronounced maxima and minima in the tree growth. Also, during some 250 years of the early growth of these trees, they show a strongly marked double-crested 11-year variation.

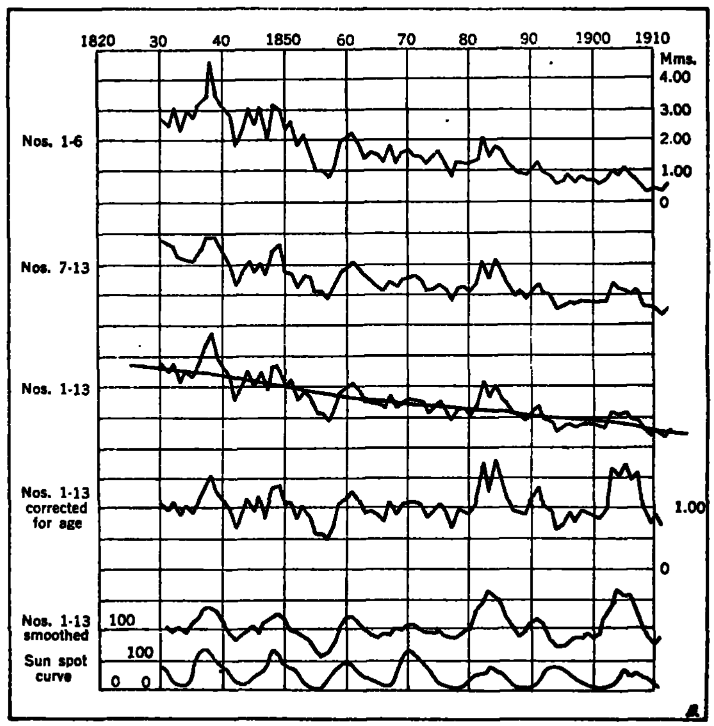

FIG. 4.—Sun spots and growth of trees at Eberswalde, Germany.

The above refers to dry climate reactions; the wet climate reaction is different, as witness the following extract:

Wet climate reaction.—In the very first group of continental trees studied, those of Eberswalde near Berlin, the remarkable fact was recognized at once that 13 trees from one of those carefully tended German forests show the 11-year sun-spot curve since 1830 with accuracy. * * * The other trees of that group do not show quite so perfect rhythm as do the marked radii shown, but are like the other parts of these sections, showing strongly a majority of the maxima. Taking the group as a whole, the agreement is highly conspicuous, and the maximum growth comes within 0.6 year of the sun-spot maxima. The Eberswalde curves arranged in two groups and compared with the sun-spot curve are shown in Figure 4 (No. 9 of original).

An explanation of the increased tree growth at Eberswalde may be found in a consideration of the precipitation record for Berlin. I have taken the five epochs of sun-spot maximum centering about 1860, 1870, 1883, 1894, and 1906 and computed the annual rainfall departure for the central year and the single year immediately preceding and following; thus the years 1859, 1860, and 1861 would represent the epoch of spot maximum of 1860. Four out of the five epochs were, on the average, periods of more than normal rainfall and but one, that of 1894, was a time of deficient precipitation. Casual inspection of the precipitation record for Berlin discloses the fact that in the 60 years 1848–1907 there were more wet than dry years, a condition directly contrary to that which is the rule in the United States, but whether this condition is common to northern Europe is not at this time known.

The concluding chapters of Dr. Douglass's work are devoted to a discussion of "Methods of Periodic Analsis," "Cycles" with an appendix giving tables of mean tree growth extending back to 1306 B. C. The book should be read by all students of weather periodicities.

CLEMENTS ON DROUTH PERIODS AND CLIMATIC CYCLES.[1]

By A. J. HENRY.

[Weather Bureau, Washington, D. C., April 1, 1922.]

Dr. Clements refers briefly to the work of Douglass [2] in relating the annual rings of trees to rainfall and the sun-spot cycle as suggesting the possibility of using the latter for forecasting the rainfall from year to year.

He also adds, seemingly in confirmation of Douglass's work, the statement that "practically all the groups of trees studied gave a clear record of growth cycles corresponding closely to the sun-spot cycle. They confirmed the hypothesis that years of sun-spot maxima were generally marked by deficient rainfall, and those of sun-spot minima by rainfall above the normal."

A preliminary examination of the rainfall records of the States west of the Mississippi River showed that the two major drouth periods of 1893–1895 and 1870–1873 coincided with sun-spot maxima. It was also evident that abundant precipitation had occurred frequently, if not regularly at times of sun-spot minima and from these facts the inference was drawn that the spot minimum of 1913 would be accompanied by an excess of rainfall and that the spot maximum of 1917 would likewise be associated with a deficit in the rainfall. Partial confirmation of these inferences led the author to make the following statements:[3]

The most attractive and promising feature of the summer's work has been the checking and tracing of the course of the present climatic cycle. The second recorded absolute minimum of no sun spots occurred in 1913 and served as the focus of a period of exceptional rainfall in the West. The drouth of the present summer (1916) in the Western and Mountain States suggests the beginning of the dry phase of the cycle. Its effect upon the carrying capacity of the ranges and upon the production of dry farms has been critical. Whether it be followed by the full period of several dry years or not, it has furnished further confirmation of the fact that all grazing and dry farming must be based upon the recurrence of dry periods; in both a scientific system of expansion and contraction must be devised to prevent disaster during dry years. If the next two or three years prove to be dry in harmony with the maximum of the sun-spot cycle, the possibility of anticipating dry seasons will be greatly enhanced. In the field of forestation much evidence has been obtained to show that planting is successful only during wet phases and that natural reproduction occurs practically only during such phases.

The investigations of climatic cycles has been continued from both the biological and astronomical approach. The former gains interest from the fact that the years 1916, 1917, and 1918 have in general been years of drouth in the West and especially the Southwest. This was suggested as a probability upon the approach of the sun-spot maximum in 1916. The maximum was passed in 1917 and attention is now centered upon the expected increase of rainfall generally as the sun-spot minimum is approached during the next four or five years. It is proposed to follow the biological effects as seen in growth, reproduction, and abundance as closely as possible and to correlate these with the climatic phases. Striking evidence of these effects have been obtained during the drouth of the past two years. By far the most important problem, however, is the relation of the sun-spot cycle to the climatic and growth cycles. There appears to be little question of the usual coincidence of these three cycles, but the existence of a causal relation is still in doubt. In the endeavor to make use of the sun-spot cycle to anticipate climatic changes, this matter is of paramount importance.[4]

The remainder of the article is devoted to an examination of the rainfall records of 23 States west of the Mississippi in an effort to establish a basic relation between rainfall and the spottedness of the sun. The method of collating the rainfall records was as follows: In the 23 States there were 323 rainfall records in 1881 and more than 1,300 in 1919. For the seventies the number was less than 100—76 in 1869, and for earlier years still less. The yearly departures of the annual totals from the normal were tabulated and classed as positive or negative by years, or rather by groups of five years, the central year of each group being the year in which the epoch of maximum sun spots occurred. The groups, therefore, center about the years 1837, 1848, 1860, 1871, 1883, 1894, 1907, and 1917. Concerning these epochs of maximum, Doctor Clements further remarks:

Since the beginning of observations in 1750 the yearly number of sun spots at the maximum has varied from 46 to 154, though the number has fallen below 80 for but 5 of the 16 maxima. For the 8 maxima considered here, the number of spots falls below 80 only in 1907 [5] and 1883, when the numbers were 62 and 64, respectively. In other words, 6 of the maxima lie above 77; i. e., half the number of spots for the highest maximum, 154.

DISCUSSION.

The chief interest in Doctor Clements's paper is, of course, the coupling of the period of solar activity manifested in the spottedness of the sun with terrestrial rainfall and the endeavor to anticipate the character of the seasonal rainfall some years in advance. I shall therefore first consider the connection between the occurrence of sun spots and rainfall.

SUN-SPOT RAINFALL RELATIONS.

Since Meldrum, in 1872, called attention to the possible connection between the phenomena above mentioned, much discussion has arisen or, rather, many persuasive reasons have been adduced in support of the idea that there must be a basic connection between the two events. It is scarcely necessary to analyze the large literature on the subject already available, but it will be desirable to touch upon the several stages of the arguments which have been advanced in support of the hypothesis.

The effort to relate sun spots with terrestrial weather dates back many years, but the specific attempt to show a relation between sun spots and *rainfall* is of comparatively recent origin. The discovery of what is popularly

---

[1] *Ecology*, Vol. II, No. 3, July, 1921.
[2] MO. WEATHER REV. 37: 225–236 and abstract of a later work in this REVIEW, immediately preceding.
[3] Carnegie Inst. Wash. Pub. No. 242, 1916.
[4] Loc. cit., pub. 304, 1917.
[5] According to Wolfer, the epoch of maximum at this time occurred in 1906.4, and the maximum number of spots was 64.2 (smoothed) in February. The epoch of 1883, according to the same authority, occurred 1883.9, and the maximum number of spots was 74.6 in November of that year.